EC486 MANAGEMENT AND ECONOMICS - 3

PRODUCTIVITY AND PRODUCTION FUNCTIONS

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Lecture 3: Overview

1. Why care about productivity?

2. Facts on productivity

3. Basic Production Functions

4. Methods of estimating production functions

5. Applications and Other issues
WHAT IS PRODUCTIVITY AND WHY SHOULD WE CARE?

• “Productivity isn’t everything, but in the long run it is almost everything” (Nobel Laureate Paul Krugman)

• Productivity growth
  – Drives growth of real wages
  – Can facilitate redistribution

• Particularly important during current era of budgetary cutbacks
Productivity

• GDP per capita (Income per person) basic indicator of economic wellbeing

• GDP per capita increases by growth of inputs (e.g. more capital or labor) or higher Total Factor Productivity (TFP)
DOWNSIDES TO PRODUCTIVITY GROWTH?

• Poverty?
  – Absolute poverty tends to fall with growth (e.g. China, India)
  – No evidence that faster productivity growth means more relative poverty/inequality

• Happiness?
  – Growth doesn’t guarantee happiness
  – Wellbeing not all about consumption (e.g. environment)
  – But big falls in consumption create misery
WHAT IS LABOUR PRODUCTIVITY? 3 COMPONENTS OF GDP (NATIONAL INCOME) PER PERSON

Basic “welfare” measure

\[
\frac{GDP}{Population} = \frac{GDP}{hours} \times \text{Labour productivity}
\]
WHAT IS LABOUR PRODUCTIVITY? 3 COMPONENTS OF GDP (OR GNP) PER CAPITA

Basic “welfare” measure

\[
\frac{GDP}{Population} = \frac{GDP}{hours} \times \frac{hours}{workers} \times \cdots
\]

Labour productivity

Choice? Labour supply
WHAT IS LABOUR PRODUCTIVITY? 3 COMPONENTS OF GDP (OR GNP) PER CAPITA

Basic “welfare” measure

\[
\frac{GDP}{Population} = \frac{GDP}{hours} \times \frac{hours}{workers} \times \frac{workers}{population}
\]

Labour productivity

Employment rate. Voluntary & Involuntary. Unemployment & inactivity

Demographics
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Productivity “Facts”

- **Macro**: Productivity varies hugely across nations and over time
  - Robert Solow: TFP growth at least as important as growth of inputs in explaining economic growth
  - Cross country GDP/capita differences largely due to TFP differences

- **Micro**: Productivity varies hugely across firms
SOME FACTS ON PRODUCTIVITY

• Aggregate growth a Total Factor Productivity (TFP) story (Solow, 1956)

• Country variation in GDP per capita & TFP closely related (Jones and Romer, 2009)

• **Reallocation** of output from low TFP to high TFP plants
  – Aggregate growth within countries (Baily et al, 1992)
  – Productivity across countries (Hsieh & Klenow, 2009)
Large GDP & TFP differences across countries

Source: Jones and Romer (2009). US=1
Large GDP & TFP differences across countries

Average US worker produces more in a day than Tanzanian in a month with same inputs

Source: Jones and Romer (2009). US=1
In long-run most countries have enjoyed catch up Growth with the GDP/head leader (US) but not all

Source: Maddison (2008) Data is smoothed by decade
Productivity differences across firms are also large

- US plants at 90th percentile have 4x higher labor productivity than plant at the 10th percentile (Syverson, 2004 REStat)
- Controlling for other inputs, TFP difference is about 2:1
- In China and India this gap is about 5:1 (Hsieh and Klenow, 2009 QJE)
DISTRIBUTION OF PLANT TFP DIFFERENCES IN US VS. INDIA
HIGHER US TFP DUE TO REALLOCATION - THINNER “TAIL” OF LESS PRODUCTIVE PLANTS

Source: Hsieh and Klenow (2009); US mean=1
TFP dispersion is particularly large in low competition industries

Source: Syverson (2004, JPE)
PRODUCTIVITY DISPERSION WITHIN COUNTRIES

• Is it all measurement problems? NO
  – cf. debate on aggregate TFP (Griliches, 1997)
  – Robust to different methods of production function estimation (see later)
  – Not just mismeasured prices: in detailed industries with plant level prices like white pan bread, block ice, concrete productivity differences still ~2:1 (Foster et al, 2008 AER)
  – Other measures of firm performance (e.g. profitability, size, management quality, etc.) show wide variation
FIRM HETEROGENEITY HAS LONG BEEN RECOGNIZED

“...we have the phenomenon in every community and in every trade, in whatever state of the market, of some employers realizing no profits at all, while others are making fair profits; others, again, large profits; others, still, colossal profits.”

Francis Walker (Quarterly Journal of Economics, ’87)
"...we have the phenomenon in every community and in every trade, in whatever state of the market, of some employers realizing no profits at all, while others are making fair profits; others, again, large profits; others, still, colossal profits."

Francis Walker (Quarterly Journal of Economics, 1887)
Productivity difference between firms is one obvious motivation for looking at management

Persistent TFP differences a key part of many Macro, Trade, IO and Labor models – but these are typically silent on the causes

Could this be in part because of differences in management? Even Adam Smith’s 1776 *Wealth of Nations* suggests this matters
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WHY ESTIMATE PRODUCTION FUNCTIONS?

Estimation of production functions has a long history closely related with panel data (e.g. farm production functions)
Interest revitalised by availability of micro-panel data on firms (company accounts like Compustat) & plants from Census Bureau of many countries (e.g. LRD in US, ARD in UK.

Why interesting?
1. Aggregative productivity growth related to shifts in the social production possibility frontier (welfare metric e.g. Hulten, 1978)
2. Economic growth mainly determined by productivity growth rather than the accumulation of inputs (Solow, 1957)
3. (Original) Are factors really paid their marginal products?
WHY ESTIMATE PRODUCTION FUNCTIONS?


5. How does this dispersion change over time (and why)? Trade Opening (Pavcnik, 2002), Deregulation (Olley-Pakes). Are the changes due to incumbent firms becoming more productive (within firm), or market share being reallocated to more productive firms, or to entry/exit?

6. Economies of scale
BASICS OF PRODUCTION FUNCTION ESTIMATION

- We want to estimate $Q_i = F (A_i, K_i, L_i)$
- $Q =$ value added (or output if include materials), $K =$ capital, $L =$ labour and $A =$ TFP.
- But we know:
  - Many of the inputs ($K, L$) are chosen by the firm, so are endogenous (Marshak and Andrews, 1944)
  - Omitted variables (Mundlak, 1961). Unless we measure this “managerial ability” (Bloom and Van Reenen, 2007) we have biased parameters
SOLUTIONS TO THE PRODUCTION FUNCTION PROBLEM

1. Residual approach
2. “External instruments”
3. Fixed effects
4. Blundell-Bond + extensions
5. Olley Pakes + extensions
COBB-DOUGLAS EXAMPLE

- \( \ln Q_i = \alpha_L \ln L_i + \alpha_K \ln K_i + \varepsilon_i \)

- \( q_i = \alpha_L l_i + \alpha_K k_i + \varepsilon_i \)

- Where \( q=\ln(Q), \ l=\ln(L), \ k=\ln(K) \)

- (More complex production functions (CES, Translog, etc.) will have same issues, but additional complexity)

- If inputs chosen before shock (e.g. Weather) then estimate by OLS
  - but this is unlikely
1. RESIDUAL APPROACH

- Solow (1957)
  - Under assumptions of competition in labour and product markets replace parameters by factor shares in revenue
  - FOC for labor and capital
  - Can extend this to relax some of competitive assumptions (e.g. Hall, 1988)

- More sophisticated versions: Data Envelopment Analysis (DEA), Stochastic Production Frontiers (SPF)
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2. IV APPROACHES (FIXED EFFECTS)

• Instrumental variables for factor inputs (L and K)

• **Candidate instruments:**
  – Input prices (Minimum wages and unions a possibility); capital tax rates for capital (e.g. Bloom, Griffith, Van Reenen, 2002; Cummins et al, 2002)

• **Problems:**
  – little variation in the cross-section,
  – input prices may be correlated with quality of inputs
3. FIXED EFFECTS (FE)

• If we have panel data then $q_{it} = \alpha_L l_{it} + \alpha_K k_{it} + \varepsilon_{it}$

• Assume “variance components” so
  – $\varepsilon_{it} = \eta_i + \tau_t + \nu_{it}$
  – Fixed effects = $\eta_i$; time dummies = $\tau_t$, $\nu_{it}$ idiosyncratic
    (i.e. uncorrelated with $\nu_{it-1}$, $\nu_{it-2}$, etc. & uncorrelated with K, L and $\eta_i$)

• Then we can estimate by classic FE
  – Include full set of dummies
  – Effectively take deviations from mean of firm and mean of year

• Problems:
  – Makes measurement error worse
  – Time-varying (correlated) shocks
4. IV AND FIXED EFFECTS ("BLUNDELL-BOND/GMM")

- Assume there are adjustment costs so that capital and labour depend on past values, e.g. $K_t = h(K_{t-1}, K_{t-2}, \text{etc.})$
  - Example of quadratic costs of adjustment
- Then implement IV-FE (Anderson-Hsiao, 1982)
- Estimate in first (or longer) differences ($\Delta$) to eliminate the fixed effects since $\Delta \eta_i = 0$
- $\Delta q_{it} = \alpha_L \Delta l_{it} + \alpha_K \Delta k_{it} + \Delta v_{it}$
- Since $\text{E}(\Delta l_{it} \Delta v_{it}) \neq 0$ & $\text{E}(\Delta k_{it} \Delta v_{it}) \neq 0$ use $l_{it-2}$ & $k_{it-2}$ as instruments for $\Delta l_{it}$ and $\Delta k_{it}$
- Valid because
  - $l_{it-2}$ & $k_{it-2}$ do not influence current productivity changes (i.e. $v_{it}$ not serially correlated
  - $l_{it-2}$ & $k_{it-2}$ will be correlated with factor inputs through adjustment costs, e.g. $k_{it} - k_{it-1} = \lambda(k_{it-1} - k_{it-2})$
PROBLEMS WITH IV FIXED EFFECTS ("BLUNDELL-BOND/GMM")

• **Inefficient**
  – Under the assumptions, not only are $l_{it-2}$ & $k_{it-2}$ IVs, but so are $l_{it-3}$ & $k_{it-3}$, $l_{it-4}$ & $k_{it-4}$
  – As panel goes on can use these to construct a GMM estimator (see Arellano and Bond, 1991)

• **Dynamics**
  – Invalidates the assumption $v_{it}$ not serially correlated
  – Can deal with this so long as serial correlation is “finite” (e.g. Blundell and Bond, 2000). Add more lags to the production
  – Example if $v_{it}$ MA(1) use just $l_{it-3}$ & $k_{it-3}$

• **Weak Instruments**
  – If capital doesn’t change much over time then lags will be weak instruments for changes in capital (e.g. If random walk hopeless)
  – Similar to problem of measurement error
5. OLLEY-PAKES

\[ q_i = \alpha_L l_i + \alpha_K k_i + \varepsilon_i \]

- Use investment to control for simultaneity problem
- Investment \( l_{it} \) is increasing in the persistent portion of productivity. In particular
  - \( l_{it} = i(\omega_{it}, k_{it}) \)
  - \( \varepsilon_{it} = \omega_{it} + \nu_{it} \)
- where \( \omega_{it} \) is known to the firm and possibly persistent (the problem!) while \( \nu_{it} \) is unknown prior to input choice and purely transitory (iid over time)
- Assume that investment chosen at \( t-1 \) determining capital at \( t \) (i.e. Capital fixed in short-run).
- **Capital** evolves deterministically \( k_t = i_{t-1} + (1-\delta)k_{it-1} \) where \( \delta \) is depreciation rate
- **Labor** is non-dynamic (only current matters)
OLLEY-PAKES

• Therefore $q_{it} = \alpha_L l_{it} + \alpha_K k_{it} + \omega_{it} + \nu_{it}$

• **OP Assume:** $\omega_{it}$ evolves exogenously following a first order Markov Process: $\omega_{it} = g(\omega_{it-1}) + \xi_{it};$ (e.g. AR(1))

• Investment strictly increasing in $\omega_{it}$: $i_{it} = i_t(\omega_{it}, k_{it})$

• “Trick” is to invert this to be $\omega_{it} = h_t(i_{it}, k_{it})$

• $q_{it} = \alpha_L l_{it} + \alpha_K k_{it} + h_t(i_{it}, k_{it}) + \nu_{it}$

• $q_{it} = \alpha_L l_{it} + \phi_t(i_{it}, k_{it}) + \nu_{it};$
  - $\omega_{it} = \phi_t - \alpha_K k_{it}$
OLLEY-PAKES: TWO STEP ROUTINE

- \( q_{it} = \alpha L_{it} + \phi_t(i_{it}, k_{it}) + \nu_{it}; \ \omega_{it} = \phi_t - \alpha K k_{it} \)

- **First stage** (to get coefficient on L):
  approximate \( \phi_t(i_{it}, k_{it}) \) non-parametrically & estimate \( \alpha_L \)
  - Example: use “series estimator” so we include polynomial terms in \( i_{it}, k_{it}, i_{it}^*k_{it}, i_{it}^*i_{it}, k_{it}^*k_{it} \)

- **Second Stage** (to get coefficient on K)
  \( q_{it} - \alpha L_{it} = \alpha K k_{it} + g(\omega_{it-1}) + \xi_{it} + \nu_{it} = \alpha K k_{it} + g(\phi_{t-1} - \alpha K k_{it-1}) \)

  Non-linear least squares
RELATIONSHIP OF OLLEY-PAKES TO OTHER ESTIMATORS

• Can actually be done in one-step GMM (Wooldridge, 2005).
• OP example of “control function” (Blundell-Powell, 2004)
• Relationship to Blundell-Bond (2000)
  – Two approaches are not-nested: (i) different timing of capital accumulation; (ii) underlying economic theory; (iii) modelling of $\omega_{it}$
  – But BB model $\omega_{it}$ as AR(1), plus fixed effect plus error. OP do not allow for a fixed effect but do allow a more general Markov process. If BB model of $\omega_{it}$ is a good approximation, then OP nested as special case of BB (perfectly flexible labor, pre-determined capital).
OLLEY-PAKES & SELECTION

• Large % of plants exit in most samples in a 5 year period
• Often researchers construct “balanced panel” using plants or firms that are active during entire period
• But balanced panel ignores selection:
  – Firms who exit are those with low productivity \( (\omega_{it}) \) draws
  – Firms with lots of capital more likely to stay even in presence of low \( w \) draws.
• Will tend to cause upward bias on capital coefficient \( \alpha_K \)
• OP use unbalanced panel & explicitly account for selection by conditioning expectation of \( \omega_{it} \) on survival
  – Model exit probability non-parametrically
SOME PROBLEMS WITH OLLEY-PAKES

• Main Ones
  1. Zero investment problem
  2. Exact multi-collinerarity

• Zero Investment problem
  – Strict monotonicity of investment rule violated in micro data because many firms report zero investment (e.g. 50% of Chilean firms)
  – Levinsohn and Petrin (2003) suggest using different proxies to control for $\omega_{it}$, e.g. Materials
SOME PROBLEMS WITH OLLEY-PAKES

• Exact multi-collinearity problem
  – Assume that markets are common & competitive
    (wage = W, price = P); i.e. no exogenous firm specific
    input price or output price shocks
  – First order conditions for labor demand implies no
    variation in labor conditional on capital

\[ l_i = \text{cons.} - (w - p) + \frac{\alpha_k k_i}{1 - \alpha_L} \]

• Solutions to multi-collinearity problem?
  – Independent variation in factor prices
  – Optimization errors
  – Timing assumptions
  – Adjustment cost for labor
  – Second moment shocks
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## Some Example Results

### Alternative Econometric Estimates of the Production Function

<table>
<thead>
<tr>
<th>Estimation Method</th>
<th>OLS Levels</th>
<th>Within Groups</th>
<th>Olley Pakes</th>
<th>GMM-SYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent variable</td>
<td>Ln(Y)_{it} sales</td>
<td>Ln(Y)_{it} sales</td>
<td>Ln(Y)_{it} sales</td>
<td>Ln(Y)_{it} sales</td>
</tr>
<tr>
<td>ln(L)_{it} labor</td>
<td>0.505</td>
<td>0.543</td>
<td>0.426</td>
<td>0.456</td>
</tr>
<tr>
<td>(0.020)</td>
<td>(0.022)</td>
<td>(0.022)</td>
<td>(0.064)</td>
<td></td>
</tr>
<tr>
<td>Ln(K)_{it} capital</td>
<td>0.128</td>
<td>0.059</td>
<td>0.156</td>
<td>0.114</td>
</tr>
<tr>
<td>(0.013)</td>
<td>(0.015)</td>
<td>(0.036)</td>
<td>(0.050)</td>
<td></td>
</tr>
<tr>
<td>ln(N)_{it} material</td>
<td>0.358</td>
<td>0.325</td>
<td>0.412</td>
<td>0.353</td>
</tr>
<tr>
<td>(0.017)</td>
<td>(0.022)</td>
<td>(0.024)</td>
<td>(0.046)</td>
<td></td>
</tr>
</tbody>
</table>

SC(1) p-value 0.000
SC(2) p-value 0.195
SARGAN p-value 0.153
SARCAN-DIF p-value 0.332
Firms 709

709 medium sized manufacturing firms, 1994-2004, UK, US, France and Germany

Source: Bloom and Van Reenen (2005), Appendix Table D1
OTHER PROBLEMS

• Measuring inputs correctly
  – Heterogeneous factor inputs (e.g. labour)
  – Labour quantity vs. labour services
  – Capital aggregation

• Measuring outputs properly
  – Unusual to have a homogenous product like “tons of cement”
PRODUCTIVITY OR MARK-UPS?

• Q is meant to be output, but actually revenues deflated with industry prices: firm prices not observed.
  – Estimated coefficients mix technological parameters with mark-ups (might want this if looking at quality)
• **Solution is:**
  – get better data on firm prices (Haltiwanger et al, 2009)
  – Explicit form of demand and jointly estimate mark-ups.
• E.g. Klette & Griliches (1996) monopolistic competition: firm specific demand function: 
  \[ q_i = -\sigma(p_i - p_I) + \nu p_I + d_i \]
  • \( p_i \) firm-specific price (unobservable), \( p_I \) is industry price (observable), \( d_I \) = industry demand shifters. \( \sigma \) = the elasticity of demand.
PRODUCTIVITY OR MARK-UPS?

- Solving for firm prices $p_i = -\frac{(q_i - \nu p_i + d_i)}{\sigma + p_i}$
- What we measure in data is real sales ($r$) not quantity ($q$)
- $r_i - p_i \equiv (q_i + p_i) - p_i$
- Putting everything together:
  \[
  q_i = \left(1 - \frac{1}{\sigma}\right)\left(\alpha_L l_i + \alpha_K k_i\right) + \frac{\nu}{\sigma} p_I + \frac{1}{\sigma} d_I
  \]
- $\sigma/(1-\sigma)$ is the inverse mark-up (a big $\sigma$ implies a smaller mark-up). The coefficient on the factor inputs mixes this with the technological coefficients
- If we have demand shifters (e.g. Industry output) $d_i$
- Then we can recover the elasticities and separate mark-ups from productivity
- De Loecker (2007) generalizes this to OP set-up
SUMMARY AND CONCLUSIONS

• Productivity perhaps the most important measure in economics
• Hard to get at technological parameters, but much recent progress
• Useful to try several methods. Relatively easy to implement in STATA
Back Up
BLUNDELL-BOND MOMENTS

• Under an initial conditions assumption (initial growth rates uncorrelated with fixed effects) then can also use lagged differences to instruments levels.
• If we have measurement error then original error is MA(1) and we get a more dynamic production function with a COMFAC restriction